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The Army requires an accurate understanding of ventilatory requirements for combat vehicle crewmen. This study was conducted to measure 3 specific ventilatory parameters in exercising soldiers so that (1) Army engineers would be able to optimize design specifications for tank air delivery systems, (2) strategists would be better able to develop doctrine regarding use of the disconnected protective mask apparatus (Mission Oriented Protective Posture Gear), and (3) military planners would be better able to predict carbon monoxide hazards for tank crewmen.

The objective of the current protocol was to measure maximal human ventilatory parameters during upper body exercise to extend the application of observations made during a previous field study of tank crewmen's ventilatory requirements[1]. This study will provide measurements of peak inspiratory flow ($\dot{V}_I$peak), estimates of alveolar ventilation ($\dot{V}_A$), and understanding of respiratory muscle fatigue.

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CHARACTERIZATION OF PEAK INSPIRATORY FLOW AND ALVEOLAR VENTILATION DURING MAXIMAL ARM CRANK EXERCISE WITH AND WITHOUT INSPIRATORY AIRFLOW RESISTANCE

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RUNNING HEAD: Peak Inspiratory Flow

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The findings in this report are not to be construed as an official Department of the Army position unless so designated by other authorized documents.

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1.0 PURPOSE AND OBJECTIVE

The Army requires an accurate understanding of ventilatory requirements for combat vehicle crewmen. This study was conducted to measure 3 specific ventilatory parameters in exercising soldiers so that (1) Army engineers would be able to optimize design specifications for tank air delivery systems, (2) strategists would be better able to develop doctrine regarding use of the disconnected protective mask apparatus (Mission Oriented Protective Posture Gear), and (3) military planners would be better able to predict carbon monoxide hazards for tank crewmen.

The objective of the current protocol was to measure maximal human ventilatory parameters during upper body exercise to extend the application of observations made during a previous field study of tank crewmen's ventilatory requirements[1]. This study will provide measurements of peak inspiratory flow ($\dot{V}_I$peak), estimates of alveolar ventilation ($\dot{V}_A$), and understanding of respiratory muscle fatigue.

2.0 PROBLEM DEFINITION AND LITERATURE REVIEW

During combat situations, armored vehicle crewmen are exposed to toxic gases which result from weapons firing, penetration events, ammunition detonation, and/or chemical weapons contamination. When threatened, soldiers donn Mission Oriented Protective Posture (MOPP) clothing. The respiratory component of the protective apparatus includes a face mask equipped with one-way valves to provide fresh air via a hose attached to a blower fan and to exhaust exhaled air into the tank turret. A filtration cannister is located on the fresh air side between the fan and mask, thus providing a continuous stream of

filtered air which is collected outside the vehicle. In the M1A1 tank, two ventilation systems are installed to deliver air under positive pressure -- a primary, fan-driven air purification system and an emergency, back-up system. The M1 tank has only one ventilation system, which is similar to the M1A1 back-up system. Both systems are designed to overcome the high airflow resistance of the respiratory protective apparatus and prevent the development of respiratory muscle fatigue in the crewmen. Ventilation system resistance has been measured at approximately 8 cm H_2O/L/sec by Weiss et al at the Chemical Research Development and Engineering Command, Edgewood, MD[2].

Current ventilation system design specifications for the M1 tank (and M1A1 back-up) require that the blower system provides a minimum airflow of 3 standard cubic feet per minute (scfm) to each crewman (approximately 85 liters per minute). In 1987, a small study performed at the Combat Systems Testing Activity found that airflow at the loader's position did meet the 3 scfm specification whereas the remaining crew positions received <3 scfm[3]. A more recent study measured ventilatory requirements of tank crewmen during simulated battlefield conditions[1] and defined the ventilatory needs for the different crew positions during average and maximal work (Table 1). The authors reported sustained and peak minute ventilations as high as 1.8 and >2.1 scfm, respectively, for loaders during firing scenarios. Unfortunately, the monitoring equipment used for the study did not measure $\dot{V}_i$peak or permit estimation of $\dot{V}_A$.

Table 1. Mean Values for Maximal and Average Ventilatory Requirements of Tank Crewmen During Simulated Battlefield Conditions

	Maximal Minute Ventilation +/- SD (scfm)	Average Minute Ventilation +/- SD (scfm)
Loaders	1.7 ± 0.3	1.2 ± 0.3
Tank Commanders	0.9 ± 0.3	0.7 ± 0.2
Gunners	0.5 ± 0.1	0.3 ± 0.1
Drivers	0.4 ± 0.1	0.4 ± 0.1

Tank ventilation systems are not physiologic because they provide continuous rather than cyclic airflow. Continuous airflow was designed to produce positive pressure inside the face mask at all times to prevent soldiers from inspiring contaminated air around the mask-face seal. However, the air flowing into the mask while the soldier is expiring is unavailible to meet his ventilatory demand. Since the expiratory portion of ventilation occupies roughly 50% of the respiratory cycle, approximately half of the airflow provided by the blower fan is not available to meet the soldier's inspiratory needs. It follows that the adequacy of the airflow system cannot be assumed from measurements of minute ventilation.

Because flow rates are greatest during the initial part of inspiration, a potential imbalance exists between the ventilation supplied by the current system (measured by $\dot{V}_I$peak) and crew members' respiratory demands. System designers are concerned that the increased ventilatory requirements resulting from increased physical exertion on the battlefield may outstrip the capacity of the air delivery system and lead to severe air hunger. If this occurs, a negative pressure will develop inside the mask which may potentially

compromise the mask's seal or compel the crewman to remove his MOPP mask, exposing him to environmental contaminants. By defining $\dot{V}_i$peak requirements, a design with optimal air-delivery specifications can be developed to prevent potential soldier injury. Prior to current studies, $\dot{V}_i$peak estimates were based on a 1973 study which demonstrated that in subjects wearing a breathing apparatus $\dot{V}_i$ peak could be approximated by multiplying minute ventilation ($\dot{V}_E$) by 2.7[4]. However, this study utilized a miner's mask with different characteristics from tankers' masks, and may not be directly applicable to tank ventilation systems.

The 1988 tank crew ventilation study demonstrated that maximal arm crank exercise closely approximated the respiratory and cardiac demands measured during the maximally stressful portion of simulated combat[1]. Therefore, a laboratory study of $\dot{V}_i$peak during maximal arm crank exercise should provide information relevant to field ventilatory requirements. In addition, the 1988 study demonstrated similar exercise performances among tank loaders and control subjects[1]. This justified the use of non-loader, soldier volunteers for the present study.

Alveolar ventilation, another parameter studied, is important to the Army because it is a critical factor affecting toxic gas exposure - particularly carbon monoxide (CO) intoxication. CO exposure is an occupational hazard of tank crewmen, and is a consequence of vehicle operation in both training and combat. Exhaust leaks from the turbine power plant, CO produced during weapons firing, or CO resulting from secondary fires within the vehicle are the primary CO sources. Currently, MIL-HDBK-759A[5] assigns a work effort level of 4 ($\dot{V}_A$ = 24 lpm) to all crewmen during combat and a work effort level of 3 ($\dot{V}_A$

= 18 lpm) at other times. Actual measurement of $\dot{V}_A$ during an exercise protocol shown comparable to a field study would enhance accuracy of predicting carboxyhemoglobin (COHb) levels with the Coburn-Forster-Kane equation[6]. In addition, physiologic variation in $\dot{V}_A$ and dead space ventilation (V_D) between rest and exercise were studied.

A third study goal was to determine a man's tolerance to the inspiratory resistance of the breathing circuit during upper body exercise. Weiss et al measured a significant pressure drop across the cannister/hose/mask combination[3] from which resistance can be calculated. However, they did not evaluate human performance while soldiers breathed through the mask combination detached from the blower fan. Such a circumstance would occur if a soldier unplugged himself from the forced air system manifold. Theoretically, the mask's inherent airflow resistance could lead to severe dyspnea and cause respiratory muscle fatigue.

In summary, this study was designed to measure soldiers' peak ventilatory requirements during upper body exercise similar to that required of a tank crew loader in combat. Respiratory measurements were made while the soldiers breathed against inspiratory workloads of similar resistance to standard tankers' masks.

3.0 MATERIALS AND METHODS

3.1 INSTRUMENTATION

The respiratory circuit (Figure 1) included a mouthpiece attached to a Hans Rudolph 3-way, non-rebreathing, low dead space valve, (#2700, Kansas City, MO) mounted in an adjustable head piece. Large, half inch diameter, low resistance, one-way valves routed

airflow properly through the mask. A nose clip was used to prevent nasal air leaks. Two thin-walled latex balloons (5 cm long and 3 cm in circumference) (Jaeger adult pressure catheters, Med Point Technologies, Inc., Rancho Cucamonga, CA) were inserted transnasally and positioned with one in the stomach and the other in the midesophagus. Balloons were placed approximately 65 and 45 cm from the nasal opening respectively and their positions were confirmed by pressure tracings. To improve patient tolerance of instrumentation during the 4 exercise sessions, each patient's nose and posterior pharynx were sprayed with a total of 2-4 ml of 1% lidocaine via an atomizer before balloon insertion. In addition, the balloon catheters were liberally smeared with 2% viscous lidocaine solution prior to placement. Each catheter was connected to a Validyne pressure transducer (Model MP45-871, Engineering Corp, Northridge, CA), and esophageal (P_{eso}) and gastric (P_g) pressures were continuously recorded on a Gould ES1000 (Cleveland, OH) strip chart recorder. Transdiaphragmatic P_{Di} pressure was measured by a Validyne differential pressure transducer (Model MP45-871, Engineering Corp, Northridge, CA) and also continuously recorded on the strip chart recorder. All pressure transducers were calibrated twice daily during the study.

A low resistance (#1) Hans Rudolph (Kansas City, MO) pneumotachometer was attached on the inspiratory side of the Hans Rudolph 3-way valve (Kansas City, MO) by a 35 mm internal diameter, corregated, rubber hose. The pneumotachometer was attached to a Validyne pressure transducer (Model MP45-871, Engineering Corp, Northridge, CA) calibrated twice daily with a reference flow measured with a laminar flow element. The output from the pneumotachometer was integrated to a volume signal and corrected to

BTPS. The pressure transducer was attached firmly to a rack, to eliminate motion artifacts. Inspiratory flow and volume signals were continuously recorded by the Gould ES1000 recorder.

To study $\dot{V}_A/\dot{V}_E$, V_D calculations were obtained by using the modified Bohr equation[7]:

$$\frac{V_D}{V_T} = \frac{P_ACO_2 - P_{emixed}CO_2}{P_ACO_2}$$

where: V_D = Dead space volume

V_T = Tidal volume

P_ACO_2 = Alveolar carbon dioxide partial pressure

$P_{emixed}CO_2$ = Mixed expired carbon dioxide partial pressure

By substituting end tidal carbon dioxide partial pressure ($P_{et}CO_2$) for P_ACO_2, V_D/V_T was calculated. $P_{et}CO_2$ values in normal subjects have been measured 1 to 7 torr below P_ACO_2[8], which would cause an approximate 2-4% error in the V_D/V_T calculation. $P_{emixed}CO_2$ measurements were performed at rest and at the completion of each 3 minute exercise level. Since the fraction of CO_2 in the mixed expired and end tidal gases are the values that were actually measured, these values were substituted in the above equation, such that final calculations of $\dot{V}_A/\dot{V}_E$ used the formula[7]:

$$\frac{\dot{V}_A}{\dot{V}_E} = 1 - \frac{V_D}{V_T} = 1 - \frac{F_{ET}CO_2 - F_{emixed}CO_2}{F_{ET}CO_2}$$

The investigators assumed V_D did not change significantly with exercise[9].

Tidal volume (V_T) was calculated from the pneumotachometer signal. Expired gases were continuously sampled (flow of approximately 10 cc/min) with a capillary tube inserted in the exhalation portion of the Hans Rudolph valve. The expired fraction of CO_2 at end expiration was measured with a Centronic 200 MGA mass spectrophotometer[R] (Suffolk, England) as $F_{et}CO_2$. The remainder of the exhaled gases entered a 16 liter mixing box, which was sampled for the $F_{emixed}CO_2$ and mixed expired oxygen fraction ($F_{emixed}O_2$) by a second capillary tube leading to the mass spectrophotometer. $F_{emixed}CO_2$ and $F_{emixed}O_2$ were measured at rest, at completion of each exercise level, and at termination of exercise. Fractional concentration of mixed expired oxygen ($F_{emixed}O_2$) measurements were made for calculation of oxygen consumption ($\dot{V}O_2$) and respiratory quotient (RQ - carbon dioxide production/ oxygen consumption). $F_{emixed}CO_2$, $F_{emixed}O_2$, and RQ data were continuously recorded and/or calculated by a 386/20E Compaq (Houston, TX) computer using DATAQ Instruments, Inc., AT-CODAS data acquisition and analysis program (Akron, OH). During exercise, continuous electrocardiographic monitoring was employed with oscilloscopic display on the Lifepack 6 Monitor/Defibrillator.

During the first week, the volunteer soldier completed an initial evaluation and exercise testing without inspiratory resistive loading. He was then tested weekly for 3 weeks with repetition of the maximal arm crank exercise protocol while inspiring through resistive valves ordinarily used to provide positive end expiratory pressure (PEEP). Three inspiratory resistances of 2.5, 7.5, and 12.5 cm H_2O/L/sec (Instrumentation Industries Inc, Bethel Park, PA) were used. The order of presentation of resistances was varied according to Latin square methodology, and the volunteers did not know which resistance level they were

working against. The middle resistor approximated Weiss' measured value for Army NBC mask apparatus respiratory resistance (7.9 $\pm$ .3 cm H_2O)[3].

Prior to initiation of the study, each valve was tested to determine its resistance profile. Precisely determined flows were applied to each resistor using a variable controlled flow generator (Powerstat^R, Superior Electric Co., Bristol, CT) and motor (Model 5H489B, Dayton Electric Manufacturing Co., Chicago, IL) while pressure drops across the valve were measured and recorded on a Gould ES1000 (Cleveland, OH) strip chart recorder. These evaluations confirmed that the PEEP valves used in this study to provide inspiratory resistance were threshold resistors with nonlinear characteristics. Resistance values for each PEEP valve are presented in Appendix 1.

3.2 EXPERIMENTAL DESIGN

This human use protocol was approved by the U.S. Army Medical Research and Development Command and the U.S. Army Office of the Surgeon General prior to its initiation. The six volunteer subjects were tested at the Department of Respiratory Research Laboratory, Building 504, Walter Reed Army Institute of Research (WRAIR), Forest Glen Annex of WRAMC. Group size was selected to match the number of subjects in the earlier tank crew study[1]. All subjects were thoroughly counselled and signed DA Form 5303-R, the Volunteer Agreement Affidavit (Appendix 2), before entering the study. Previously formulated volunteer inclusion criteria had specified 18-32 year old soldiers who were assigned to WRAIR or Walter Reed Army Medical Center (WRAMC). Three exclusionary criteria were: (1) current cigarette smoking, (2) current regular performance of recreational upper body exercises such as weight lifting, swimming, or rowing, and (3)

serious cardiopulmonary disease discovered by history or physical examination.

Fasting subjects were studied on four consecutive Wednesday mornings with testing performed in an environmentally controlled building. The men began their evaluations with completion of a medical questionnaire and brief physical examination. Next resting 12-lead electrocardiogram (Sensormedics ECG Horizon System^{R}, SensorMedics Corp., Anaheim, CA) and pulmonary spirometric testing (SRL M10-0473 Automated Spirometer^{R}, SRL Controls Div., Dayton, OH) were performed. At least three forced vital capacity (FVC) maneuvers were accomplished. To provide test accuracy, the sum of the FVC and the forced expired volume in one second (FEV_1) had to agree within 5% on three determinations. Because the exercise task was no more strenuous than routine military tasks (such as the Army physical fitness test), no additional medical evaluations were required. Pertinent data recorded during the physical examination included age, height and weight. Total body fat percentile was calculated from triceps skin fold thickness measurements taken with the Lange Skinfold Calipers^{R} (Cambridge Scientific Industries Inc., Cambridge, MD) utilizing standard methodology. Atmospheric pressure measurements were recorded daily with a mercury barometer.

Arm crank exercise was performed on seated subjects utilizing a Monark Rehabilitation Trainer^{R} ergometer (Monark-Crescent AB, Varberg, Sweden) mounted on a table with pedals adjusted to each subject's heart level. Because subjects were not firmly secured to the chair, exercise actually involved the entire upper body musculature rather than being isolated to the arms. Each subject maintained the crank rate of 70 revolutions per minute, previously shown to maximize oxygen uptake[10]. The power output began at 35

watts and increased by 35 watts every 3 minutes until the maximal voluntary level had been reached. Although the literature does not describe a "standard" protocol for upper body exercise, this protocol is similar to previous reports[11], and has been shown to approximate closely the cardiopulmonary response during tank firing exercises in the field[1].

During exercise testing each subject was evaluated with continuous cardiac monitoring with a Lifepak 6 Monitor-Defibrillator^R (Physio-Control Corp., Redmond, WA) to detect occult cardiac disease. During the first three weeks of exercise testing, subjects were monitored transcutaneously for oxyhemoglobin saturation levels. None of three different oximeters used (Criticare 501+^{R}, Criticare Systems Inc, Milwaukee, WI, Biox 3700^R, Ohmeda Corporation, Boulder, CO, or Lifestat 1600^R, Physiocontrol Corp, Redmond, WA) provided reliable data. At baseline and at every subsequent minute, heart rate, oxygen saturation, and mixed expired CO_2 were measured. Inspiratory time (T_i), total time of the respiratory cycle T_{tot}), inspiratory flow, Peso, Pg, Pdi, respiratory rate, and V_T were continuously recorded. To obtain ordinal measurements of these parameters which were continuously printed out in hard copy by the strip chart recorder, the investigators averaged values from five consecutive breaths taken at baseline and during each 30 second interval before the workload was increased and/or the subject stopped exercising. $\dot{V}O_2$, $\dot{V}CO_2$, $\dot{V}_E$, and RQ were calculated every 10 seconds by the computer.

For each exercise task, maximal exercise was determined by the subject's inability to continue. The time to exhaustion was measured for each exercise task. To assess subjective perception of exercise difficulty, a rating scale for perceived exertion (RPE) was completed after each task (utilizing the open-ended Borg Scale shown in Figure 3), to

determine the subject's degree of skeletal muscle (M), cardiopulmonary (C), and generalized (G) fatigue at exercise termination[12]. In addition, throughout each exercise period physician investigators continuously monitored each subject for chest pain, syncope, or electrocardiographic evidence of myocardial ischemia (ST segment depression of equal to or greater than 1 mm or significant ventricular arrhythmias). The data from each exercise task were evaluated statistically using the analysis of variance method. Statistical significance was assumed present if $p \leq .05$.

4.0 FINDINGS

4.1 BASELINE EXERCISE TESTING (WITHOUT INSPIRATORY RESISTANCE)

Baseline history and physical examinations were performed on all subjects. None had a known history of serious cardiopulmonary diseases. Physical examinations were totally unremarkable except that 2 asymptomatic subjects were noted to have irregular apical pulses. Electrocardiographic testing revealed rate-related, Wenckebach, second-degree, bundle branch block in one individual and rate-related, premature atrial and ventricular contractions in the other. The other 4 volunteers had normal electrocardiograms. Physical characteristics of the 6 study subjects are shown in Table 2.

Subjects age-predicted maximal heart rates (HR_{max}) were calculated using the following regression equation[13]:

$$HR_{max} \text{ (beats/minute)} = 210 - .65 \text{ (age)}$$

At maximal exercise, the mean percentage of predicted HR_{max} achieved was 88%. Values ranged from 72-97%, and are presented in Table 3.

To further evaluate the intensity of subjects' exercise output, measured maximal $\dot{V}O_2$ values were compared to predicted $\dot{V}O_2$max values utilizing the following regression equation[14]:

$$\dot{V}O_2max = 3.45 * Height(m) - 0.028 * Age(yr) + 0.022 * Weight(kg) - 3.76$$

These calculated values were then multiplied by a correction factor of 0.73, because arm crank $\dot{V}O_2$max has been shown to approximate 73% of treadmill $\dot{V}O_2$max[8]. Soldiers' mean value for measured maximal $\dot{V}O_2$/kg was 100% of the predicted arm crank $\dot{V}O_2$max, with values ranging from 75-132% (Table 4).

4.2 EXERCISE TESTING AGAINST INSPIRATORY RESISTANCE

To determine whether study subjects had provided comparable maximal efforts during each exercise repetition, HR_{max}, maximal $\dot{V}O_2$/kg, and exercise duration were evaluated (Figures 4,5, Table 5). There was no statistically significant change noted in any of these parameters. Therefore, data for these parameters from the maximal exercise studies with resistive loads were compared to the maximal exercise studies without resistive loads.

Three parameters did change significantly in response to added inspiratory resistances: $\dot{V}_E$, $\dot{V}_i$peak, and RPEs for cardiopulmonary and generalized fatigue (Figures 6-8, Table 5,6). Mean values for $\dot{V}_E$ at maximal exercise decreased from 2.6 scfm (73.1 lpm) at baseline to 1.6 scfm (46.5 lpm) at maximal inspiratory resistance (Figure 6), while the mean values for $\dot{V}_i$peak at maximal exercise decreased from 9.5 scfm (270 lpm) to 5.5 scfm (156 lpm) (Figure 7).

Ratings of perceived exertion at maximal exercise indicated no significant change in fatigue of the upper body musculature, but did demonstrate a significant increase in subjective perception of cardiopulmonary and generalized fatigue when exercising against all inspiratory resistive loads (Figure 8).

Although mean values for P_{Di} were not significantly changed by inspiratory resistive loading, 4 of 6 subjects were unable to increase P_{Di} appropriately when breathing against the highest inspiratory resistor (Figure 9). The 2 subjects whose P_{Di} values increased continuously were the most muscular individuals. Measurements of P_{eso} and P_g increased as expected during exercise and showed no indication of paradoxic diaphragmatic movement. Inspiratory time (T_i) was compared to the time for the entire respiratory cycle (T_{tot}) and the ratio (T_i/T_{tot}) during exercise was not significantly affected by increases inspiratory resistance.

Oxygen saturation readings during exercise were unreliable. None of 3 different oximeters was capable of recording accurate data.

RQ values were calculated and recorded at 10 second intervals. Although RQ increased appropriately during most exercise trials, the absolute values for RQ are unexpectedly high. This raises questions about the accuracy of the $\dot{V}O_2$ and/or $\dot{V}CO_2$ measurements.

Dead space to tidal volume ratios at maximal exercise were not significantly affected by inspiratory resistive loading. Mean V_D/V_T at rest was 30% and decreased to 4-10% with maximal exercise.

Alveolar ventilation was calculated to determine the effect of inspiratory resistive loading. Mean $\dot{V}_A$ at maximal exercise was 2.4 scfm (69 lpm) without inspiratory resistance; all 3 inspiratory resistances decreased $\dot{V}_A$ significantly to values averaging between 1.4-1.8 scfm (40-50 lpm).

The ratio of $\dot{V}_i$peak to $\dot{V}_E$ decreased from a mean of 3.8 to 2.8 with the addition of inspiratory resistance. These changes were not statistically significant. Although both the $\dot{V}_i$peak and $\dot{V}_E$ were decreased by inspiratory resistive loading, reductions in $\dot{V}_i$peak were proportionately greater.

5.0 DISCUSSION

In this study, volunteer subjects were asked to perform 4 trials of maximal arm crank exercise against varying inspiratory workloads. One workload (7.5 cm H_2O/L/sec) approximated the resistance measured for the MOPP facepiece, hose, and filtration canister[3]. The other resistances were chosen to add work at levels above and below the MOPP apparatus. When resistor characteristics were studied by varying airflow through the resistors (Appendix 1), the 7.5 and 12.5 cm H_2O/L/sec resistors were found to have similar profiles at airflow values comparable to those measured on study subjects. Therefore, data are reported for the 12.5 cm H_2O/L/sec resistor.

To assess consistency of exercise performances, we evaluated the following parameters achieved at maximal exercise: exercise duration, heart rate, and maximal $\dot{V}O_2$. Mean data for the 6 subjects showed no statistically significant changes in any of these variables and thus demonstrate that subjects performed similarly each repetition of maximal

exercise. We attribute subject's consistent performances to their exceptional motivation.

Mean values for HR_{max} were >85% of age-predicted maximal heart rate, indicating acceptable exercise performance for the group as a whole. HR_{max} and maximal $\dot{V}O_2$/kg values were compared to a previous laboratory and field study and were found to be within similar ranges[1]. Mean values for measured maximal $\dot{V}O_2$/kg were 100% of predicted and were not changed significantly by increasing inspiratory resistance.

The mean value of $\dot{V}_E$max was significantly decreased by the addition of inspiratory resistance. All 5 subjects whose $\dot{V}_E$max decreased demonstrated slowing of the respiratory rate (from a mean of 51 to 39 breaths/min). Mean V_T increased from 1.5 to 1.7 L/min. These data are in agreement with previous reports and indicate that the physiologic response to inspiratory resistive loading is slow, deep breathing.

Aldrich has defined muscle fatigue as an exertion-induced, reversible decrease in muscle strength or a decrease in the force exerted by muscle in response to a given load[15]. When an exhausting workload is applied to a muscle, the subject will stop the activity or will work until fatigue develops. In this study, P_{Di}max values achieved by 4 of the 6 subjects plateaued or decreased during exercise against the 12.5 cm H_2O/L/sec resistance indicating diaphragmatic muscle fatigue. The 2 subjects whose P_{Di}max values increased progressively were the largest, most muscular individuals studied. Evidence of diaphragmatic fatigue was further assessed by measuring the diaphragmatic duty cycle and by evaluating P_{eso} and P_g for evidence of diaphragmatic paradox. The duty cycle measures T_i relative to T_{tot}. As T_i/T_{tot} increases, muscle rest and endurance decrease[16]. In the study subjects, mean T_i/T_{tot} values at maximal exercise did not change significantly as inspiratory resistance increased.

Diaphragmatic paradox would have been manifested by paradoxic inward displacement of the abdominal wall during inspiration but was not found, when P_{cso}, P_g and P_{Di} tracings were studied. In summary, we believe that the inspiratory resistances used in this study affected inspiratory muscle strength at maximal exercise in 4 of 6 subjects, but because of the limited exercise duration did not adversely impact performance.

Pandolf et al have developed ratings of perceived exertion to assess subjective components of exercise[12]. Using their ratings system, maximal exercise intensity was evaluated on 3 scales; upper body muscle (M), cardiopulmonary (C), and generalized (G) fatigue. Subjects were not aware of their responses from previous weeks nor did they know which inspiratory resistance they were working against. Increasing inspiratory resistance did not change perceived exertion of the upper body musculature; subjects reported that their muscles felt equally exhausted at completion of each task. On the other hand, perceptions of both C and G fatigue increased significantly as inspiratory resistance increased. Killian & Jones have related the intensity of breathlessness to peak inspiratory pressure, which, itself, reflects the peak tension developed by the inspiratory muscles[17]. The data suggest that exercising subjects did perceive added inspiratory resistive workloads at the levels of resistance studied (including the resistance level previously measured for the tank crewman's MOPP mask[3]). Although our highly motivated subjects were able to complete similar maximal exercise during laboratory testing despite inspiratory resistive loading, battlefield performance could be degraded to unacceptable levels by additional stressors such as fear and high ambient temperatures inside armored vehicles.

We were unable to perform reliable assessments of transcutaneous oxygen saturation during exercise, despite using 3 different brands of oximeters. Other authors have noted no loss of reliability occurring at maximal exercise, but their reports describe bicycle ergometry rather than upper body exercise[18]. While it is unlikely that these young, healthy subjects desaturated significantly during exercise, objective data measuring oxyhemoglobin saturation levels are lacking. Killian & Jones do state that when normal subjects breathe against progressive inspiratory loads to the point of intolerable dyspnea, both hypoxemia and hypercarbia may result[17].

During all data collections, respiratory quotient (RQ) calculations were performed by the computer system every 10 seconds, based upon $\dot{V}O_2$ and $\dot{V}CO_2$ measurements. The values obtained are unrealistically elevated, with most subjects appearing to be anaerobic at rest and exercise. We did note appropriate, progressive increases in RQ during exercise in all subjects, indicating some degree of reliability of the data.

Calculations V_D/V_T ratios and $\dot{V}_A$ were made from $F_{et}CO_2$ and $F_{emixed}CO_2$ measurements. Before exercise, mean V_D/V_T was 30%, while at maximal exercise mean V_D/V_T ratios decreased to 4-10% and were not significantly affected by inspiratory resistance. Calculated V_D/V_T values are in close agreement with published values of approximately 25-35% at rest and 5-20% during maximal exercise[19]. The mean value for calculated maximal $\dot{V}_A$ was 2.4 scfm (69 lpm) and was decreased significantly to the 1.4-1.8 scfm (40-50 lpm) range by all inspiratory resistances studied. Even if these values are imprecise because expired gases were sampled rather than alveolar and arterial blood gases, $\dot{V}_A$ is far in excess of the 24 lpm value used in MIL-HDBK-759A to predict CO toxicity[5].

For tank loaders performing simulated or actual battlefield scenarios, a work level of 5 ($\dot{V}_A$ = 30 lpm) should be used for prediction of CO toxicity.

While this study was designed to address issues of particular military relevance, its, findings can be generalized to civilian occupations performed by individuals wearing positive pressure masks (e.g. fire fighters, sandblasters, boiler scalers, etc.). NIOSH criteria specify that such workers receive at least 4 scfm (approximately 114 lpm) of airflow[20]. Our data show that values for $\dot{V}_i$peak at maximal exercise average 9.5 scfm (270 lpm) without inspiratory resistance and 5.5 scfm (156 lpm) against the maximal inspiratory resistance tested. Therefore, at peak workload, the inadequate system flow will cause air hunger and increased risk of contaminated air entrainment through the mask-face seal. For the military M1 tank crewman, these potential risks are compounded further by the fact that the collective ventilation system is designed to provide only 3 scfm of continuous airflow to each soldier of which only about half is available during inspiration.

In the 1989 report of tank crewmen's ventilatory requirements, field equipment limitations did not allow measurement of $\dot{V}_i$peak[1]. Rather, $\dot{V}_i$peak values were estimated using the relationship reported by Bentley et al[4] that at maximal workload $\dot{V}_i$peak approximately equalled 2.7 * $\dot{V}_E$. Data from this study showed that the $\dot{V}_i$peak/V_E ratio was 3.8 without inspiratory resistive loading and decreased to 2.8 with maximal resistance. These observations agree with Bentley's[4], but only at high levels of inspiratory resistance.

6.0 CONCLUSIONS

a. The addition of inspiratory resistive loading to soldiers performing maximal arm crank exercise did not degrade performance, although subjects perceived greater dyspnea and fatigue. This exercise task is functionally comparable to the work performed by a tank crew loader engaged in a battlefield scenario.

b. During battle in a contaminated environment, additional stressors such as high ambient temperature and fear could possibly degrade loader performance.

c. Measured values for peak inspiratory flow at maximal exercise averaged 9.5 scfm without inspiratory resistance and were decreased to 5.5 scfm by the highest resistance studied. Both values significantly exceed the 3.0 scfm airflow design specifications for the ventilation system aboard the M1 tank (which is the back-up system on the M1A1 tank). OSHA recommended airflow in the civilian workplace (4 scfm) is also exceeded. To prevent soldier injury caused by inhalation of contaminated air around the mask, airflow through the system should be designed to exceed 5.5 scfm during inspiration to the loader.

d. The calculated value for $\dot{V}_A$ at maximal exercise was 69 lpm (2.4 scfm) without inspiratory resistive loading and was decreased significantly to 40-50 lpm (1.4-1.8 scfm) by all 3 inspiratory resistors. All values far exceed the $\dot{V}_A$ of 24 lpm used in MIL-HDBK-759A to predict CO toxicity in working loaders. For these predictions, a work level of 5 ($\dot{V}_A$ = 30 lpm) should definitely be used.

e. Diaphragmatic fatigue appeared to develop in the majority (4 of 6) of individuals performing maximal exercise against increased inspiratory resistance. Exercise performance was not degraded.

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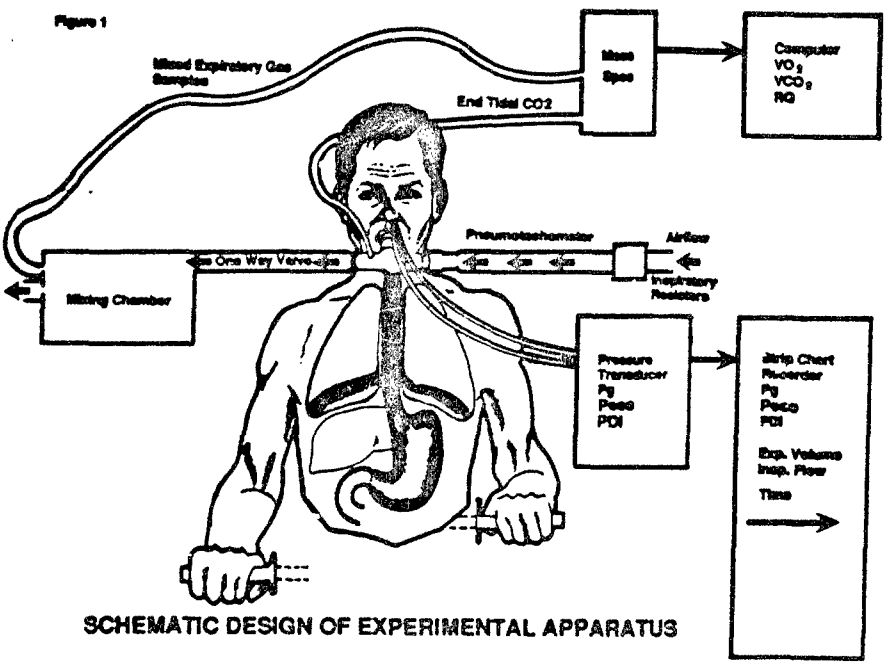

SCHEMATIC DESIGN OF EXPERIMENTAL APPARATUS

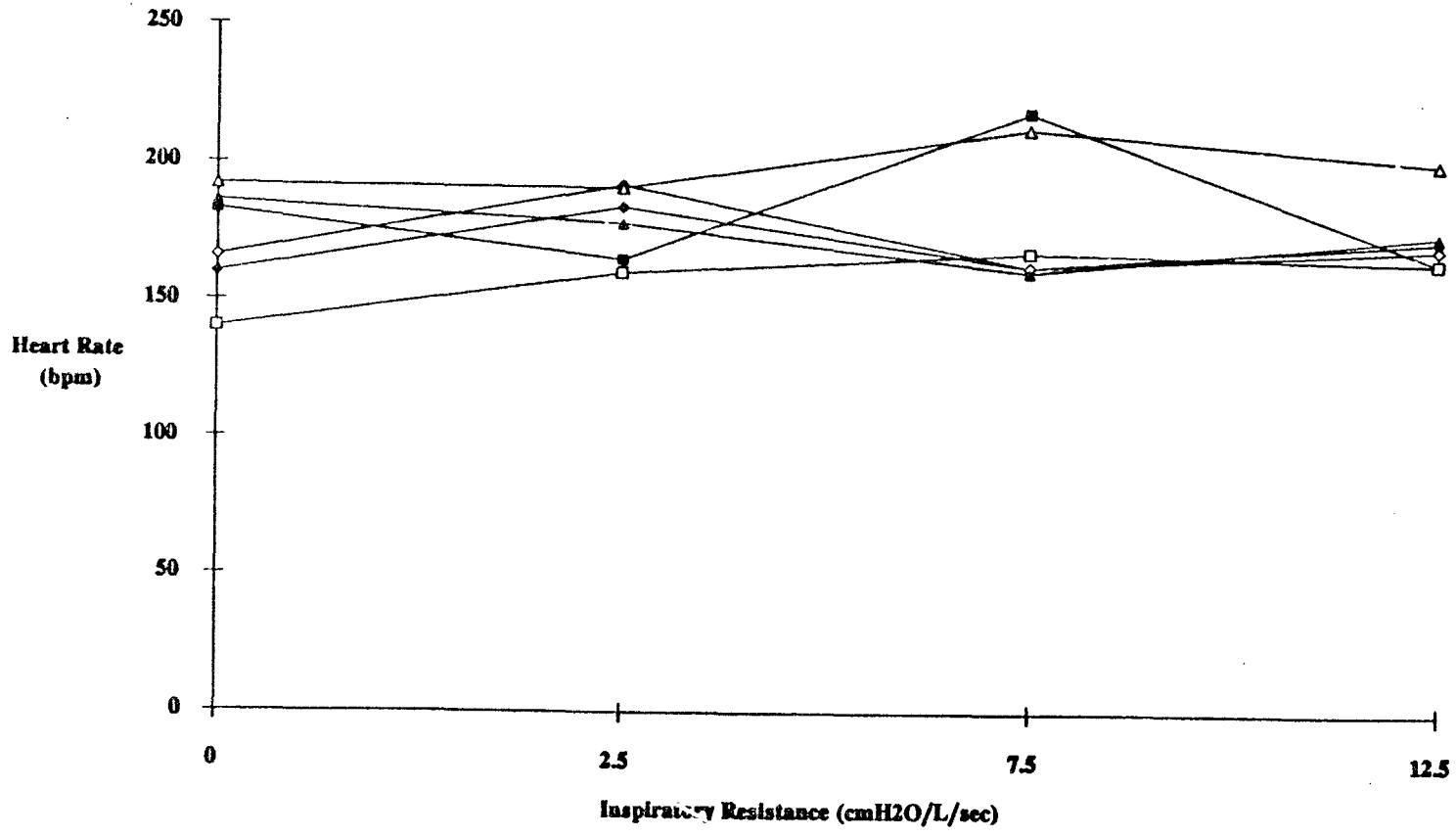

Figure 4: Heart Rate at Maximal Exercise vs Inspiratory Resistance

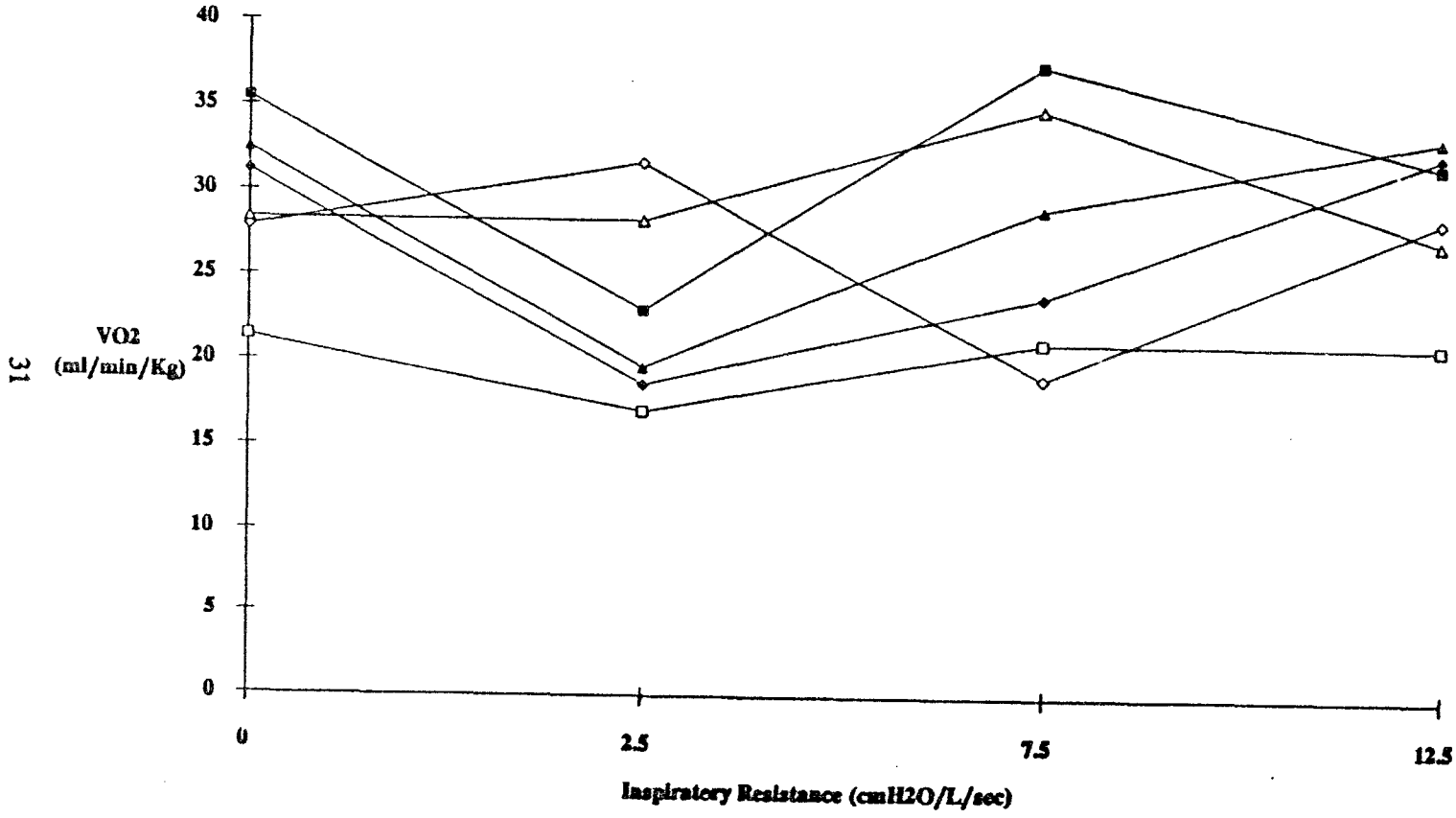

Figure 5: Oxygen Consumption per Kilogram Body Weight at Maximal Exercise vs Inspiratory Resistance

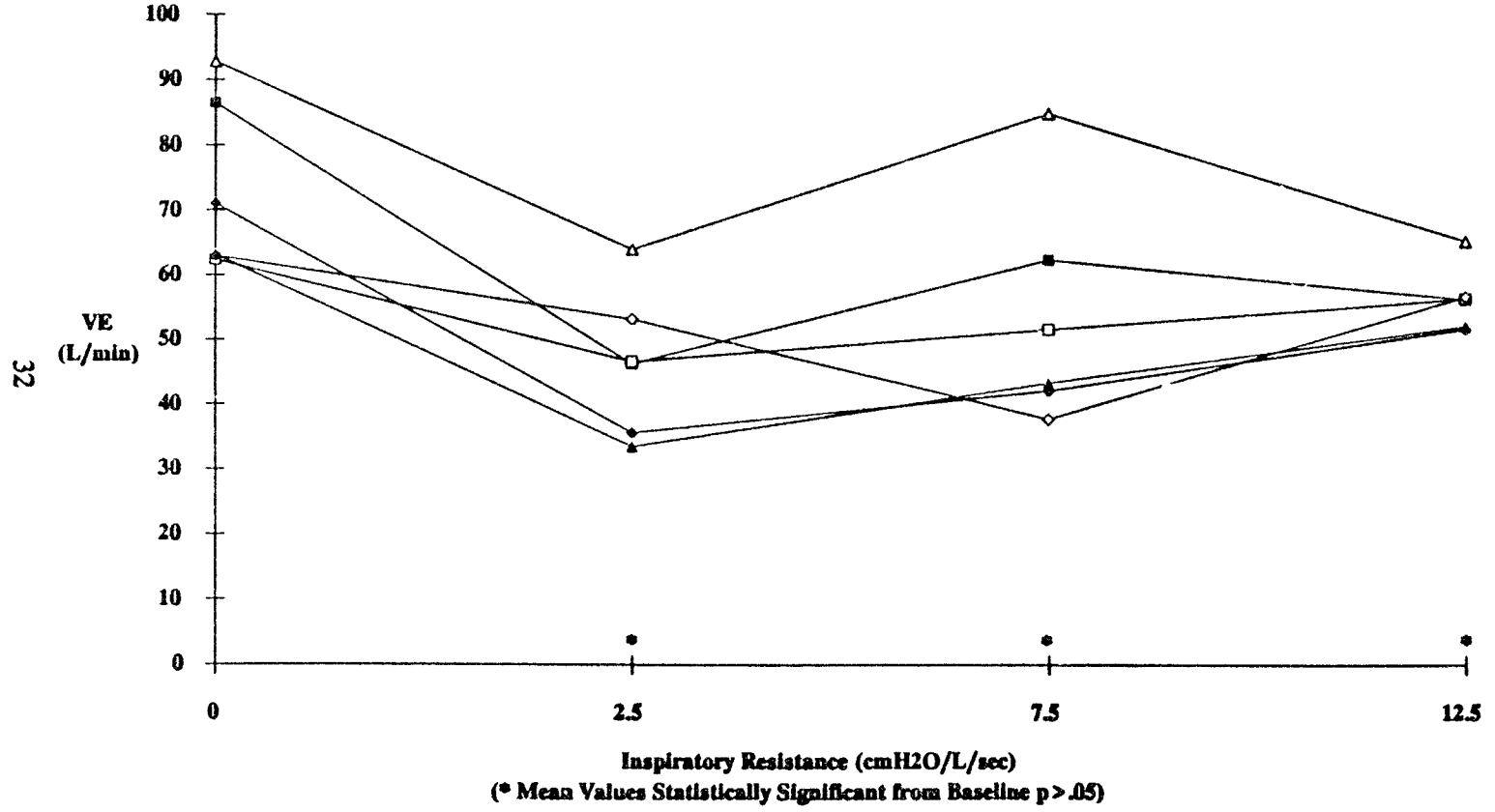

Figure 6: Minute Ventilation at Maximal Exercise vs Inspiratory Resistance

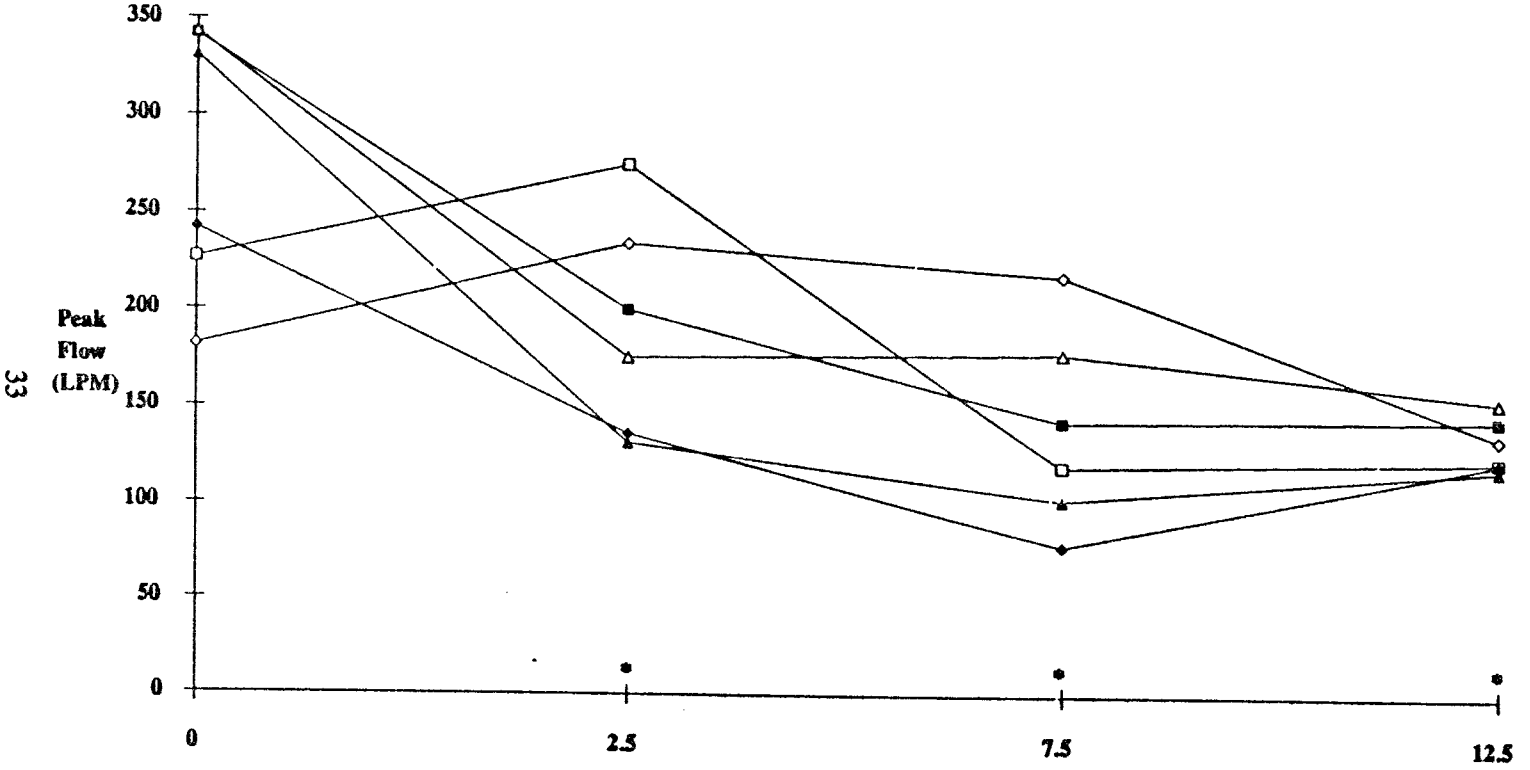

Figure 7: Peak Inspiratory Flow at Maximal Exercise vs Inspiratory Resistance

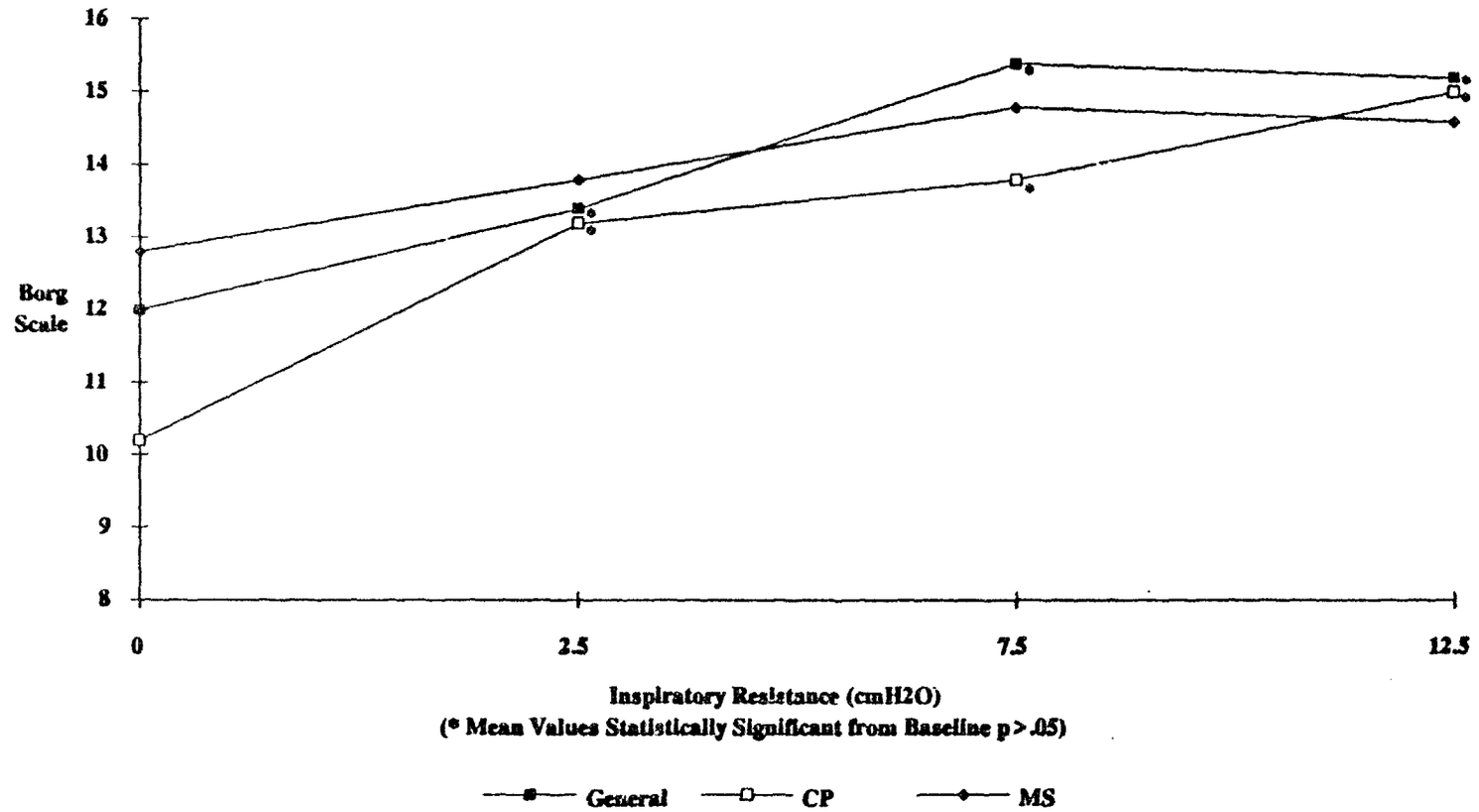

Figure 8: Rating of Perceived Exertion at Maximal Exercise vs Inspiratory Resistance

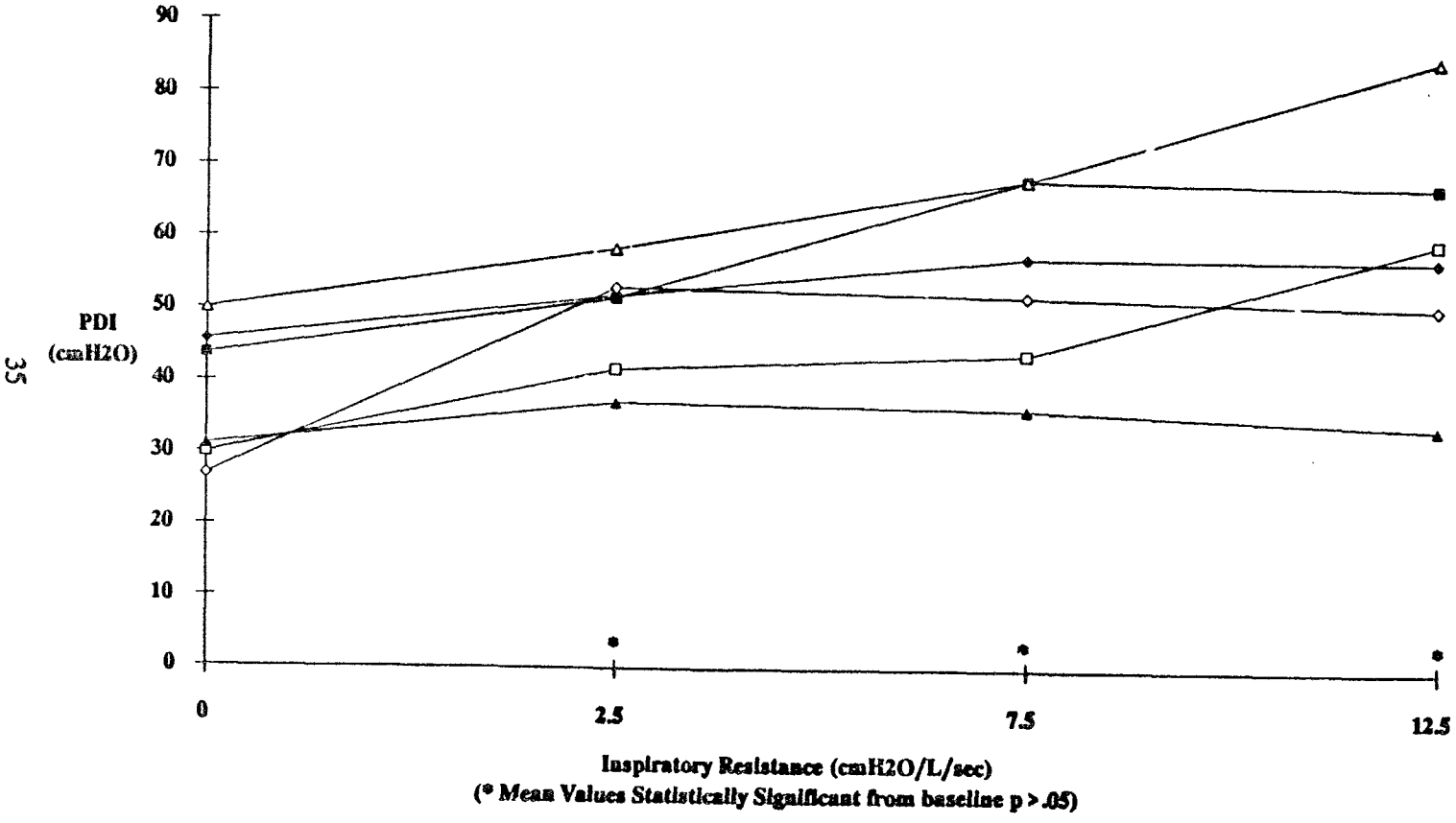

Figure 9: Transdiaphragmatic Pressure at Maximal Exercise vs Inspiratory Resistance

Table 2. Physical Characteristics of Control and Study Subjects

Subject	Age (yr)	Height (cm)	Weight (kg)	%ile Fat	FVC (% Pred)	FEV1 (% Pred)	FEV1% (%)
1	25	180	91	60	96	102	85
2	23	174	69	40	125	125	80
3	28	152	67	75	101	98	84
4	27	173	93	85	95	99	78
5	29	177	75	40	148	137	77
6	20	171	64	25	125	133	87
MEAN	**25**	**171**	**77**	**54**	**115**	**116**	**82**

Table 3. Percent of Maximal Age-Predicted Heart Rate Achieved Against Different Inspiratory Resistances

		Level of Inspiratory Resistance			
	Age Predicted HR_{max}	0	2.5 cm	7.5 cm	12.5 cm
1	194	99	98	110	104
2	195	85	98	84	87
3	192	83	96	85	90
4	192	73	83	88	86
5	191	91	86	115	86
6	197	94	90	82	89
MEAN		**88**	**92**	**94**	**90**

Table 4. Percent of Maximal Age-Predicted Oxygen Consumption Achieved Against Different Inspiratory Resistances -- Corrected for Upper Body Exercise

		Percentage of $\dot{V}O_2max/kg$			
	Age Predicted $\dot{V}O_2max/kg$	0	2.5 cm	7.5 cm	12.5 cm
1	30.1	94	94	117	91
2	33.0	85	96	58	87
3	23.7	132	79	88	137
4	27.4	78	62	78	77
5	31.0	115	75	122	103
6	34.1	95	58	86	98
MEAN		**100**	**77**	**92**	**99**

Table 5: Physiologic Responses at Maximal Exercise Against Increasing Inspiratory Resistance

	Exercise Duration				Max Heart Rate				Max Respiratory Rate				Vt			
Resistance/ Subject	0.0	2.5	7.5	12.5	0.0	2.5	7.5	12.5	0.0	2.5	7.5	12.5	0.0	2.5	7.5	12.5
1	12.0	12.0	12.0	12.0	183.0	165.0	219.0	165.0	49.0	34.0	18.0	32.0	1.9	1.6	3.5	3.1
2	9.5	9.0	9.0	9.0	140.0	160.0	168.0	165.0	41.0	38.0	32.0	41.0	1.5	1.2	1.6	1.4
3	9.2	9.0	9.0	9.0	160.0	184.0	163.0	173.0	57.0	40.0	42.0	33.0	1.2	0.9	1.0	1.6
4	9.0	9.0	9.0	9.0	166.0	192.0	163.0	170.0	55.0	21.0	36.0	42.0	1.4	2.5	1.0	1.6
5	12.0	9.0	9.0	9.0	186.0	178.0	161.0	175.0	56.0	33.0	33.0	26.0	1.2	1.3	2.1	2.1
6	12.0	12.0	12.0	12.0	192.0	191.0	266.0	201.0	47.0	32.0	36.0	36.0	2.0	2.0	2.4	2.1
Mean	10.6	10.0	10.0	10.0	171.2	178.3	190.0	174.8	50.8	33.0	32.8	35.0	1.5	1.6	1.9	2.0
Stdev	1.5	1.5	1.5	1.5	19.6	13.4	43.4	13.5	6.3	6.6	8.1	6.0	0.3	0.6	1.0	0.6
p-Value (p>.05)										*	*	*				

	Maximal VE (lpm)				Maximal VO2/kg (ml/min/kg)				Pdi				Ti/Tt			
Resistance/ Subject	0.0	2.5	7.5	12.5	0.0	2.5	7.5	12.5	0.0	2.5	7.5	12.5	0.0	2.5	7.5	12.5
1	86.5	46.3	62.5	56.4	35.5	23.1	37.7	31.9	43.7	51.8	68.4	67.9	0.5	0.6	0.6	0.6
2	62.4	46.6	51.6	56.5	21.4	17.1		21.2	29.9	41.9	44.2	60.1	0.7	0.4	0.6	0.4
3	71.1	35.7	42.1	51.8	31.2	18.7	24.0	32.5	45.7	52.1	57.6	57.6	0.4	0.5	0.6	0.5
4	63.0	53.2	37.7	56.8	27.9	31.8	19.2	28.7	26.9	53.2	52.2	51.1	0.6	0.5	0.6	0.6
5	63.2	33.5	43.3	52.2	32.5		29.2	33.5	31.1	37.3	36.6	34.4	0.5	19.7	0.6	0.5
6	92.8	64.1	85.0	65.5	28.4	28.4	35.1	27.4	50.0	58.6	66.4	85.4	0.6	0.6	0.7	0.6
Mean	73.2	46.6	53.7	56.5	29.5	23.8	29.0	29.2	37.9	49.2	54.6	59.4	0.6	3.7	0.6	0.5
Stdev	13.3	11.3	17.7	4.9	4.8	6.3	7.6	4.6	9.7	7.9	12.9	17.0	0.1	7.8	0.0	0.1
p-Values (p>.05)		*	*	*						*	*	*				

	Peak Flow				Vd/Vt				Va			
Resistance/ Subject	0.0	2.5	7.5	12.5	0.0	2.5	7.5	12.5	0.0	2.5	7.5	12.5
1	342.0	201.0	144.0	301.2	1.0	0.1	0.1	0.2	43.7	9.0	11.2	35.2
2	226.8	276.0	120.6	124.8	0.5	0.6	0.2	0.3	56.2	40.5	45.4	27.2
3	242.4	136.8	79.2	124.2	0.5	0.4	0.3	0.3	68.3	29.3	38.3	33.9
4	181.8	235.2	219.6	136.8	0.2	0.3	0.3	0.2	59.9	17.7	32.8	49.4
5	331.2	132.0	103.2	120.6	0.3	0.3	0.3	0.1	58.1	31.5	35.5	51.7
6	343.2	176.4	179.4	156.0	0.3	0.4	0.2	0.3	90.9	56.4	70.6	47.7
Mean	277.9	192.9	141.0	160.6	0.5	0.3	0.2	0.2	62.9	30.7	39.0	40.9
Stdev	69.7	56.4	51.6	70.1	0.3	0.2	0.1	0.1	15.9	16.7	19.3	10.0
p-Value (p>.05)		*	*	*						*	*	*

Table 6: Effects of Ratings of Perceived Exertion at Maximal Exercise by Inspiratory Resistance

	General				Cardio-Pulmonary				Musculo-Skeletal			
Resistance/ Subject	0.0	2.5	7.5	12.5	0.0	2.5	7.5	12.5	0.0	2.5	7.5	12.5
1	14.0	13.0	18.0	16.0	10.0	13.0	15.0	14.0	14.0	16.0	16.0	16.0
2	10.0	12.0	16.0	16.0	10.0	12.0	16.0	18.0	7.0	12.0	14.0	15.0
3	13.0	14.0	14.0	14.0	10.0	15.0	13.0	15.0	10.0	13.0	14.0	15.0
4	10.0	13.0	15.0	14.0	10.0	11.0	13.0	14.0	14.0	13.0	15.0	13.0
5	10.0	13.0	12.0	15.0	10.0	13.0	13.0	15.0	13.0	13.0	12.0	12.0
6	13.0	14.0	18.0	17.0	11.0	14.0	15.0	17.0	13.0	14.0	17.0	17.0
Mean	11.7	13.2	15.5	15.3	10.2	13.0	14.2	15.5	11.8	13.5	14.7	14.7
Stdev	1.9	0.8	2.3	1.2	0.4	1.4	1.3	1.5	2.8	1.4	1.8	1.9
p-Values (P>.05)		*	*	*		*	*	*				

10.0 APPENDIX

Appendix 1: Characteristics of Valves Used to Provide Inspiratory Resistance

Valve	Flow (L/sec)	Pressure Drop (cm H_2O)	Calculated Resistance (cmH_2O/L/sec)
2.5 cm	1	4	4
	2	14	7
	3	25	8.3
	4	39	9.8
	5	54	10.8
	6	76	12.7
	7	90	12.9
	8	108	13.5
7.5 cm	1	8	8
	2	19	9.5
	3	35	12.7
	4	52	13
	5	70	14
	6	88	14.7
12.5 cm	1	12	12
	2	19	9.5
	3	33	11
	4	49	12.3
	5	67	13.4
	6	83	13.8

APPENDIX 10.2

VOLUNTEER AGREEMENT AFFIDAVIT

For use of this form, see AR 40-38; the proponent agency is Office of the Surgeon General

THIS FORM IS AFFECTED BY THE PRIVACY ACT OF 1974

1. AUTHORITY: 10 USC 3012, 44 USC 3101 and 10 USC 1071-1087.

2. PRINCIPAL PURPOSE: To document voluntary participation in the Clinical Investigation and Research Program. SSN and home address will be used for identification and locating purposes.

3. ROUTINE USES: The SSN and home address will be used for identification and locating purposes. Information derived from the study will be used to document the study; implementation of medical programs; teaching; adjudication of claims; and for the mandatory reporting of medical condition as required by law. Information may be furnished to Federal, State and local agencies.

4. MANDATORY OR VOLUNTARY DISCLOSURE: The furnishing of SSN and home address is mandatory and necessary to provide identification and to contact you if future information indicates that your health may be adversely affected. Failure to provide the information may preclude your voluntary participation in this investigational study.

PART A - VOLUNTEER AFFIDAVIT

VOLUNTEER SUBJECTS IN APPROVED DEPARTMENT OF THE ARMY RESEARCH STUDIES

Volunteers under the provisions of AR 70-25 are authorized all necessary medical care for injury or disease which is the proximate result of their participation in such studies.

I, _____ SSN _____ having
(last, first, middle)

full capacity to consent and having attained my _____ birthday, do hereby volunteer to participate in
Characterization of Peak Inspiratory Flow and Alveolar Ventilation during
(research study)
Maximal Arm Crank Exercise with and without Inspiratory Airflow Resistance

under direction of LTC K. Torrington conducted at WRAIR
(name of institution)

The implications of my voluntary participation; the nature, duration and purpose of the research study; the methods and means by which it is to be conducted; and the inconveniences and hazards that may reasonably be expected have been explained to me by
K. Torrington, M.D., LTC MC

I have been given an opportunity to ask questions concerning this investigational study. Any such questions were answered to my full and complete satisfaction. Should any further questions arise concerning my rights on study-related injury I may contact
The Staff Judge Advocate, USAMRDC

at Fort Detrick, Frederick, MD 21701. Phone (301) 663-2065 (AV 343-2065)
(name and address of hospital & phone number (Include area code))

I understand that I may at any time during the course of this study revoke my consent and withdraw from the study without further penalty or loss of benefits however, I may be ☐ required (military volunteer) or ☐ requested (civilian volunteer) to undergo certain examination if, in the opinion of the attending physician, such examinations are necessary for my health and well-being. My refusal to participate will involve no penalty or loss of benefits to which I am otherwise entitled.

PART B - TO BE COMPLETED BY INVESTIGATOR

INSTRUCTIONS FOR ELEMENTS OF INFORMED CONSENT: (Provide a detailed explanation in accordance with Appendix E, AR 40-38 or AR 70-25.)

VOLUNTEER STATEMENT

You and five other soldiers are volunteering to participate in a research project designed to study breathing requirements of combat vehicle crewmen. The Army needs this information to provide optimal specifications for breathing systems designed for armored combat vehicles. The study will not benefit you directly.

Your testing will occur in 1990 at the Department of Respiratory Research, Walter Reed Army Institute of Research, at the WRAMC Forest Glen Annex, Washington, D.C. Initially, you will complete a brief medical questionnaire, physical examination, breathing test and electrocardiogram. These procedures will help investigators discover any unknown illnesses which might prevent you from performing exercise tests. None of these tests will be embarrassing or painful, and you will not have blood or urine specimens collected. If any serious heart or lung condition is detected, you will not be chosen for the study, and you will be referred to the appropriate clinic at WRAMC.

If you are accepted as a volunteer, you will begin exercise tests one day each week for four weeks. You will be sitting on a chair with a special bicycle which you will pedal with your arms. Every 3 minutes, pedalling will become harder until you can no longer crank the pedals. The exercise will probably last only 10-12 minutes each time, but it will be hard work. You might have to quit because your arms wear out or because you become short of breath. Or, although it is unlikely, you might become dizzy or experience muscle cramps or chest pain. During exercise, if you are found to have a serious heart or lung problem, or if you somehow hurt yourself, you will also be referred to WRAMC for care. A doctor will be in attendance at all times that you are exercising.

During testing, you will breathe into a clean, rubber mouthpiece attached to an apparatus to measure your air. A soft noseclip will prevent air from leaking from your nose. You will be wearing electrodes on your chest to monitor your heart. In addition, you will be required to swallow 2 long, thin tubes, which have been inserted through your nose into the back of your throat. One tube will be placed in your stomach and the other in the esophagus (food tube). Each tube is approximately 1/16 inch in diameter and each has a soft balloon at its tip. The balloons will be inflated with air, after the tube has been placed where we want it to be located. Before you swallow the tubes, your nose and throat will be sprayed with a numbing medication (1% Lidocaine) to prevent any pain, nausea, or gagging. Other less likely problems caused by the tubes are nosebleeds or fainting. We want to emphasize that if the tubes cause problems (such as the ones mentioned above), you will be eliminated from the study. By stopping, you will not face any penalty or loss of benefits. In fact, you may refuse to continue to participate in the study at any time.

If you have any questions or problems during this study, contact LTC Kenneth Torrington, Pulmonary Disease Service, Walter Reed Army Medical Center, Washington, D.C. 20307-5001. The telephone number is (301) 576-1745 (Autovon 291-1745). The scientific data obtained from these tests will be reviewed by representatives of the U.S. Army Medical Research and Development Command. Test results will be published in either an Army technical report or a scientific journal, but all volunteer exercise participants will remain anonymous.

After you have signed this form, you will receive a copy of it.

_____

Signature of Principal Investigator/Organization

SIGNATURE OF VOLUNTEER	DATE SIGNED	SIGNATURE OF LEGAL GUARDIAN (If volunteer is a minor)
PERMANENT ADDRESS OF VOLUNTEER	TYPED OR PRINTED NAME AND SIGNATURE OF WITNESS	DATE SIGNED

11.0 LIST OF SYMBOLS AND ABBREVIATIONS

bpm	Beats per Minute
STPD	Standard Temperature Pressure Dry (mm Hg)
C	Cardiopulmonary Fatigue Rating of Relative Perceived Exertion
cm H_2O/L/sec	Centimeters of Water per Liter per Second (Units of Resistance)
CO	Carbon Monoxide
COHb	Carboxyhemoglobin
EKG	Electrocardiogram
f	Respiratory Frequency
$F_{emixed}CO_2$	Fractional Concentration of Mixed Expired Carbon Dioxide (%)
$F_{et}CO_2$	Fractional Concentration of End Tidal Carbon Dioxide (%)
F_eO_2	Fractional Concentration of Expired Oxygen (%)
FEV_1	Forced Expired Volume in One Second (liters)
FVC	Forced Vital Capacity (liters)
G	Generalized Fatigue Rating of Relative Perceived Exertion
HR	Heart Rate
HR_{max}	Maximal Heart Rate
kg	Kilogram
lpm	Liters per Minute
M	Muscle Fatigue Rating of Relative Perceived Exertion
max	maximum
maximal $\dot{V}O_2$	Measured Maximal Oxygen Consumption
MIL HDBK 759A	Military Handbook 759A
min	Minute
ml	Milliliter
mm Hg	Millimeters of Mercury
MOPP	Mission Oriented Protective Posture
O_2	Oxygen
% Pred	Percent of Predicted
P_b	Barometric Pressure (mm Hg)
P_{Di}	Transdiaphragmatic Pressure (mm Hg)
P_{eso}	Esophageal Pressure (mm Hg)
P_g	Gastric Pressure (mm Hg)
P_{H2O}	Pressure of water vapor (mm Hg)
pO_2	Partial Pressure of Oxygen (mm Hg)
RPE	Rating of Relative Perceived Exertion
scfm	Standard Cubic Feet per Minute
SD	Standard Deviation
T_i	Inspiratory Time (seconds)
T_{tot}	Total time of the Respiratory Cycle (seconds)
T_i/T_{tot}	Respiratory Duty Cycle
$\dot{V}_A$	Alveolar Ventilation (lpm)

V_D	Dead Space Volume (ml)
$\dot{V}_E$	Minute Ventilation (lpm)
$\dot{V}_i$peak	Peak Inspiratory Flow Measured
$\dot{V}CO_2$	Volume of Carbon Dioxide Produced (lpm)
$\dot{V}O_2$	Volume of Oxygen Consumed (lpm)
$\dot{V}O_2$max	Predicted Maximal Oxygen Consumption
V_T	Tidal Volume
WRAIR	Walter Reed Army Institute of Research
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